Understanding Students' Confusion and Interest in an Introductory Physics Course Through Qualitative Analysis of Self-Reflections

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Research Background

Reflection refers to the process by which individuals revisit, analyze, and evaluate their experiences to derive meaning and insights (Gibbs, 1988). In educational contexts, students' self-reflections include valuable information about their learning processes, such as how they interpret, engage with, and achieve the objectives set by their instructors (Boud et al., 1985). Thus, by analyzing reflections, educators gain a deeper understanding of students' cognitive and emotional responses to instruction (Boud et al., 1985). Collecting and analyzing self-reflections submitted by students, the present study explores what aspects of a college-level introductory physics course students find confusing and interesting. We focused on confusion and interest due to their significance in understanding students' learning experiences and improving physics courses.

Confusion can be a valuable lens for examining student learning in STEM (Science, Technology, Engineering, and Mathematics) education. Confusion is widely recognized in science education as a natural and essential learning component, particularly when students encounter new or challenging concepts (Chi et al., 1994). It has been described as a cognitive-affective state that arises when there is a perceived discrepancy between one's expectations and actual understanding (Pachankis, 2007). While confusion is often viewed as a negative emotion, research suggests it can play a productive role in learning when coupled with motivation and appropriate support (D'Mello, 2013; D'Mello et al., 2014). For example, D'Mello (2013) highlights the importance of 'productive confusion,' where learners grapple with ambiguity or errors, ultimately leading to deeper engagement and understanding. In physics education, confusion can stem from abstract concepts, complex problem-solving, or unfamiliar instructional strategies. By identifying what confuses students, educators can design targeted interventions to support resolution and foster a deeper understanding of the material.

Fostering interest is also critical in STEM education, as it enhances engagement and supports long-term learning and retention (English, 2016). Interest is often regarded as a positive affective state that drives student engagement and motivation in learning (Schiefele, 1991). It is typically categorized as either situational interest, which arises from external stimuli, or individual interest, which reflects a sustained personal connection to the subject (Schiefele, 2009). Research shows that situational interest can be sparked by instructional techniques that make content relevant, surprising, or emotionally engaging (Harackiewicz et al., 2008; Nachtigall & Rummel, 2021). STEM education offers numerous opportunities to promote interest through real-world applications, hands-on experiments, and intriguing phenomena, such as wave interference or conservation principles. Understanding what students find interesting during lectures gives STEM instructors insights into effective teaching practices and strategies to sustain curiosity and motivation.

Considering the significance of confusion and interest in STEM education, we will investigate the following research questions in the context of an introductory physics course: RQ1) What aspects of lectures do students most frequently and least frequently identify as confusing? RQ2) How is students' academic performance related to the content of their reflections on confusing parts of lectures? RQ3) What aspects of lectures do students most frequently and least frequently identify as interesting? RQ4) How is students' academic performance related to the content of their reflections on interesting parts of lectures? While addressing these four research questions, we observed a significant overlap in the focus of reflections between confusion and interest. Thus, we added an additional research question: RQ5) How often are the focuses of reflections on confusing and interesting aspects of lectures similar to each other?

Several prior studies provide a foundation for understanding the relationship between confusion, interest, and student learning. Research on scaffolding emphasizes the importance of providing structured support to address conceptual and procedural challenges, particularly in physics education (Belland et al., 2011; Sarwar & Trumpower, 2015). Additionally, the role of metacognitive development in fostering reflection and problem-solving skills has been emphasized as an area for instructional improvement (Bell et al., 2018; Nurulain Mohd Rum & Zolkepli, 2018). Meanwhile, studies on student engagement reveal that integrative approaches connecting concepts to real-world applications enhance interest and participation, even in traditionally lecture-based courses (Henderson et al., 2011; Means et al., 2016). Furthermore, the interplay between affective states, such as confusion and curiosity, has been explored. Previous studies (D'Mello, 2013; Fayn et al., 2019; Jirout, 2020) suggested that confusion can catalyze deeper engagement and intellectual curiosity when guided appropriately. Various veins of works collectively inform this study's investigation into how confusion and interest overlap in shaping student reflections and engagement in an introductory physics course.

This study addresses a significant research gap in three ways. First, it examines how students engage with challenging material in a foundational STEM course, an area where limited research has explored student reflections in the context of physics education. The students in this study were enrolled in the Introductory Physics for Science and Engineering course, a one-semester (16-week) course designed to support first-year STEM majors in developing fundamental physics knowledge applicable to their disciplines. The course covered topics such as mechanics, wave phenomena, and thermodynamics, emphasizing problem-solving and conceptual understanding. Second, the study's findings are based on a semester-long dataset and thus provide a more comprehensive view of student learning compared to prior studies that often rely on shorter-term data collection. Such an extended timeframe allows for deeper insights into students' evolving engagement and learning experiences. Significantly, the instructor of the course was not involved in data analysis to ensure the independence of the study. Third, the study addresses a notable gap in the existing literature: the lack of research investigating the relationship between confusion and interest in educational contexts. By examining the overlap between such cognitive-affective states, this study provides unique insights into how students engage with challenging material. The findings offer a foundation for designing instructional strategies in physics courses that simultaneously address confusion and foster interest, thereby contributing to more effective teaching and learning practices.

Method

Participant

Participants of this study were 90 undergraduate students at a public university in the Northeastern region of the United States. The students were enrolled in the course, ' Introductory

Physics for Science and Engineering,' which lasted for one semester (sixteen weeks). The course was designed to support first-year STEM major students in attaining fundamental physics knowledge that will be used in their disciplines. The instructor was not involved in our study's data analysis. The Institutional Review Board (IRB) approved the recruitment of participants. Students in the courses were asked to reflect on their learning after each lecture during an academic semester.

Data collection using the reflection-prompting mobile application

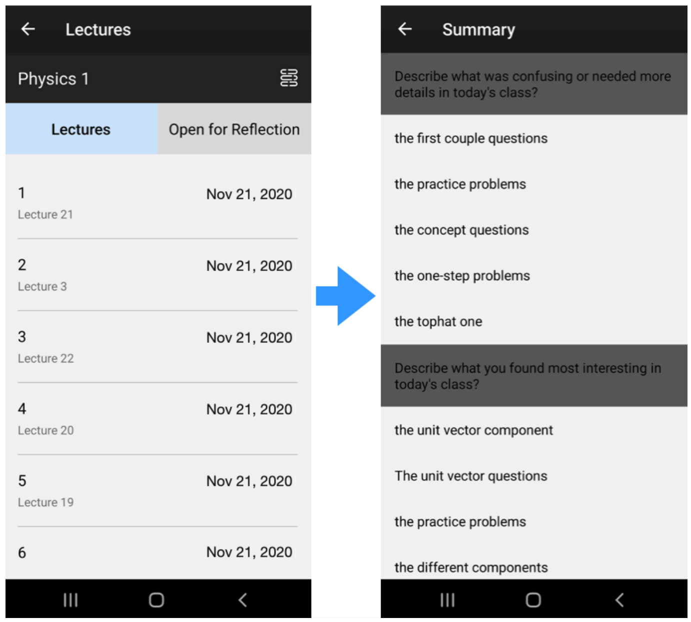

Figure 1. An example screenshot of the reflection-prompting mobile application

To collect semester-long data, we used an existing mobile application, which was developed to prompt and collect students' self-reflection and in-situ feedback. This app collects data from student reflections to help instructors identify students' difficulties and provide additional feedback and support for student learning throughout the semester.

Figure 1 shows an example of the application's user interface. On the left of this figure, students could choose one of the lectures they are taking. After selecting one lecture, they were asked to answer four self-reflection guides: 'Describe what was confusing or needed more details in today's class,' 'How much confusing was it? Rate on a 1-5 scale,' 'Describe what you found most interesting in today's class,' and 'How much interesting was it? Rate on a 1-5 scale.' The students were given a specified timeframe to submit their reflections on each lecture.

As seen on the right of Figure 1, the students and the instructor could see the summarized list of responses for both questions. Data collection through the app started after IRB approved the study. The students were encouraged to use the app, but it was not mandatory. Reflection data collected via this app was tracked only by the researchers, and we used anonymized IDs for each student who agreed to participate in the study. The instructor had access only to the summaries of reflections that were automatically generated from the reflections. Hereafter, 'confusion reflections' stands for students' reflections on confusing parts of lectures, while 'interest reflections' refers to students' reflections on interesting parts of lectures. In total, 820 confusion reflections and 820 interest reflections were collected. Each reflection consisted of one or two sentences, and sometimes three sentences.

Data Analysis

Three researchers, the first author and two of the co-authors of this paper, analyzed self-reflections that the students typed following these two questions: 'Describe what was confusing or needed more details in today's class' and 'Describe what you found most interesting in today's class.' We conducted both inductive and deductive coding processes (Saldaña, 2015, pp. 14–18, 72–80).

First, taking the inductive approach, the researchers explored the collected data and searched for relevant previous studies. We found Chi and VanLehn's (1991) study to be the most pertinent because the students' self-reflections mainly consisted of self-explanation as to why they were confused about and interested in what they learned in each lecture. Second, we developed an a priori code scheme using the four categories of constituent knowledge: 1) self-reflection on understanding systems, 2) self-reflection on executing the technical procedure, 3) self-reflection on understanding physics principles, and 4) self-reflection on understanding physics concepts.

Third, using the deductive approach, the three researchers independently coded 10 % of the total reflections to discuss elaborating the a priori coding scheme. As a result, we generated codes for each of the four categories and added the fifth and sixth categories: 5) self-reflection on instructional strategies and 6) metacognition. The seventh category was also created to label reflections without confusion or interest. Table 1 shows the finalized coding scheme that includes the description of the six categories and the nineteen codes. The last column of Table 1 shows two examples of each code selected from the confusion and interest reflections.

Lastly, the three researchers coded the remaining 90% of the data using the finalized coding scheme outlined in Table 1. To ensure consistency, we employed an iterative approach: in the first round, we independently coded 10% of the data. At this stage, the inter-rater reliability (IRR) was below 0.80, indicating the need for greater alignment. To address this, we extracted reflections with differing labels, discussed the rationale behind each label, and revised the coding based on mutual agreement, following the suggested iterative process for achieving satisfactory inter-rater reliability (Hemmler et al., 2022).

Following such discussions, we coded another 10% of the data independently. This process resulted in an IRR slightly exceeding 0.80. With sufficient consistency established, we proceeded with a divide-and-conquer approach for the remaining data. The primary coder coded 70% of the remaining data, while the other two researchers independently coded half of this subset (35% each). For quality assurance, inter-rater reliability was assessed as follows. For one-half (35% of the data), IRR was measured between the main and second coders. For the other half, IRR was measured between the main coder and the third coder. This strategy ensured that the analysis remained systematic and reliable while optimizing the workload distribution among researchers. The final IRR was 0.76 (Cohen's Kappa).

Table 1. Finalized coding scheme to answer RQ1-RQ4

Name of Code	**Description of Code**	**Example (Raw Response)**	
		Confusion reflection	**Interest reflection**
Technical Procedure *category captures reflections focused on procedural skills for understanding, applying, and interpreting physics systems, principles, and concepts. Students often reflect on "how to" accomplish specific tasks, demonstrating their engagement with the technical aspects of physics.*			
Mathematical Calculation	Reflections on general mathematical processes, such as vector analysis or equation-based calculations. This code includes reflections where students describe calculation methods or strategies used to approach physics problems.	“How to determine if the answer to the cross product or dot product is positive or negative.”	“it was cool to me that you could directly treat it like one with regards to adding them (at least with regards to that problem).”
Graphical Interpretation/ Representations	Reflections that involve interpreting, creating, or using visual representations (graphs, charts, diagrams). This code includes both the understanding and production of graphical elements to illustrate or analyze physics concepts.	“I'm having trouble visualizing the problems. Like where to extend the axis to make the force and radius perpendicular to each other”	“the graphical version of position vs. velocity vs. acceleration was an interesting and helpful concept to know and see”
Formula Derivation	Reflections on the derivation or proof of formulas. This code expresses confusion or interest in the process of developing equations to describe physical phenomena.	“how will we need to derive the Specific inertia equations in exams and quizzes”	“How the force of gravity on earth is just derived from the gravity eqn.”
Problem-Solving Setup	Reflections focused on the methods or steps to approach physics problems. Typically, these reflections use terms like "problem," "question," or "practice question" and describe how to structure problem-solving strategies.	“I thought the second concept question was confusing because I was unsure if I should assume that the ball would still reach the top of its circular path”	“I found the puck question the most interesting along with the yeti. They were both thought provoking. I found the puck one really interesting because it gave three vectors to add which made it slightly more challenging.”

<table>
<tr><td>Application of Principles/ Concepts</td><td>Reflections questioning how or when to apply specific equations, principles, or methods. Students explicitly express uncertainty/interest about the context for using particular principles or about the application to real-world situations.</td><td>“I was confused about understanding all the situations that this concept of a found gravity can be applied in.”</td><td>“The rocket problems are interesting to connect physics to real life examples.”</td></tr>
<tr><td colspan="4">Principle category captures reflections that focus on understanding the "how" or "why" behind physics phenomena, laws, or theories. Students express a desire to understand the foundational principles governing physical events.</td></tr>
<tr><td>Principle of Phenomenon</td><td>Reflections describing the mechanisms behind specific phenomena. These reflections often address "how" or "why" a phenomenon occurs, emphasizing cause-and-effect relationships within specific contexts. A mere description of a phenomenon cannot be labeled as this code.</td><td>“I still don't understand why frequency gets higher as an object moves towards you vs away from you.”</td><td>“The problem about pushing or pulling a sled, in particular how the angle you push an object changes the force you need to move it”</td></tr>
<tr><td>Principle of Physics Law/ Rule/ Theory</td><td>Reflections on the underlying logic or reasoning behind fundamental physics laws, rules, or theories, such as conservation laws. These reflections focus on understanding the general principles without a specific event or scenario.</td><td>“I experienced confusion over the right-hand rule and how that worked with the angular velocity and acceleration.”</td><td>“How mechanical energy is a combination of kinetic energy and potential energy”</td></tr>
<tr><td colspan="4">Reflections in this System category provide insights into students' mental models of entire systems or configurations, such as blocks on inclined planes. Reflections include references to relationships among system components and often highlight how different parts interact within the whole.</td></tr>
<tr><td>System and Component</td><td>Reflections discussing an entire system or individual components within it, like elements of a block-pulley setup. This code captures reflections about how different parts of a system work together, helping students contextualize their understanding of physics systems.</td><td>“Relative motion was confusing, especially the question on the concept quiz with the ball and the pitching machine and the truck.”</td><td>“We had one of the same problems with two people pulling a rope on each side and the tension in the rope is between both of their forces”</td></tr>
<tr><td colspan="4">Concept category covers reflections on broad physics concepts that do not detail specific applications or explanations, often capturing a student’s conceptual focus or confusion.</td></tr>
</table>

Physics Terminology/ Equation/ Formula	Reflections centered on physics terms or symbols, definitions, nature, characteristics, and fundamental meanings in relation to equations or formulas. This code is used when students express confusion/interest about the basic understanding of terms, distinct from procedural questions about their application.	“what represents the breaking point in the equations provided?”	“I found the idea that gravity is of different (slight) values different places on earth cool”
Relationships Between Concepts	Reflections describing similarities, differences, or cause-and-effect relationships between physics concepts. Students may discuss how one factor influences another or the connections among related concepts.	“I was struggling to understand the intertidal vs. noninertial situations.”	“Learning about the similarities between torque and angular momentum made sense to me”
Miscellaneous	Brief reflections that mention general concepts like force, motion, or energy but lack detailed context. This code applies when a reflection uses physics terms without clarifying why the concept is confusing or interesting.	“The speed of a wave was confusing for me”	“Static equilibrium for multiple axes”
*Reflections in **Instruction** category focus on students' perceptions of the instructional process rather than the content itself, providing feedback on the effectiveness of teaching methods.*			
Clarity of Instruction	Reflections addressing whether explanations were clear or confusing. Students typically use terms like "clear" or "unclear" to describe their experience.	“It seemed like some people didn't quite know how Tophat was going to work, and missed out on partial question points by not submitting an answer.”	“The explanation of potential energy was interesting and easy to understand”
Pacing of Content	Reflections on the speed or pacing of instruction. This code applies when students comment on whether the material was presented too quickly/slowly or perfectly/properly for comprehension.	“the static equilibrium explanation was a little bit confusing because it moved quickly”	“The timing of it was nice.”

Teaching Methods and Materials	Reflections describing specific teaching methods, multimedia resources, or tools, like problem examples or interactive systems (e.g., TopHat). Students share feedback on how these instructional elements affected their understanding.	“The explanation of rotational and translational motion was a bit confusing to combine the topics.”	“I loved how you outlined your teaching style! It was awesome to get insight into how you want to run the class.”
Metacognition *category encompasses reflections focused on students' self-awareness and personal learning experiences unrelated to specific physics content or instruction.*			
Progress Monitoring	Reflections on students’ self-assessment of their learning progress. These reflections indicate awareness of improvement, stagnation, or confusion, with students tracking their own development.	“I am a little confused about the last example we were doing, but when I thought over after class, I figured out the answers.”	“I found the COM stuff the most interesting because I had some trouble understanding it in the videos and the lecture cleared things up.”
Learning from Mistakes	Reflections on recognizing and correcting errors, often highlighting how mistakes served as learning opportunities.	“(...) Unfortunately, I got tricked on the first question but after that I did really well.”	“(...) It took a lot of trial and error for me to think of the correct way, but it was interesting.”
Connection to Previous Knowledge	Reflections that connect new material to prior knowledge, learning materials, or experiences, including comparisons or recall of past learning. For instance, students might relate new physics concepts to prior topics or courses, demonstrating continuity in their learning journey.	“(...) I have already taken 2 years of physics, so I know this content very well and is something I'm very comfortable with. ”	“What I found most interesting in today's video lectures is the connection of the graphs from previous lessons and other subjects.”
Incomplete *category includes reflections that are ambiguous, lack detail, or explicitly state a lack of confusion or interest.*			
Unclear Focus	Reflections that are too brief or ambiguous to determine specific content confusion, lacking mention of physics terms, equations, or concepts.	“Boat example”	“Tension”
No Confusion/ Interest	Reflections in which students state explicitly that they experienced no confusion or interest in the material.	“I don't think there was anything very confusing about today”	“(...) I didn't really find any of it that interesting”

Result

We counted the frequency of each code to quantify the results of qualitative analyses (Chi, 1997). The code *Miscellaneous* under the category *Concept* and all codes under the category *Incomplete* were not actively included in findings and discussions despite the high frequency. A group (n = 34) and B group (n = 48) refer to students whose grades were A+, A, A- and B+, B, and B-, respectively. Because the number of students whose grades were C+ or lower (n = 8) was significantly lower than the other two groups, we did not focus on analyzing such students' data separately. The number of confusion reflections was 373, 382, and 65 from the A, B, and C groups, respectively. The number of interest reflections was the same.

Reflections on confusing parts of lectures

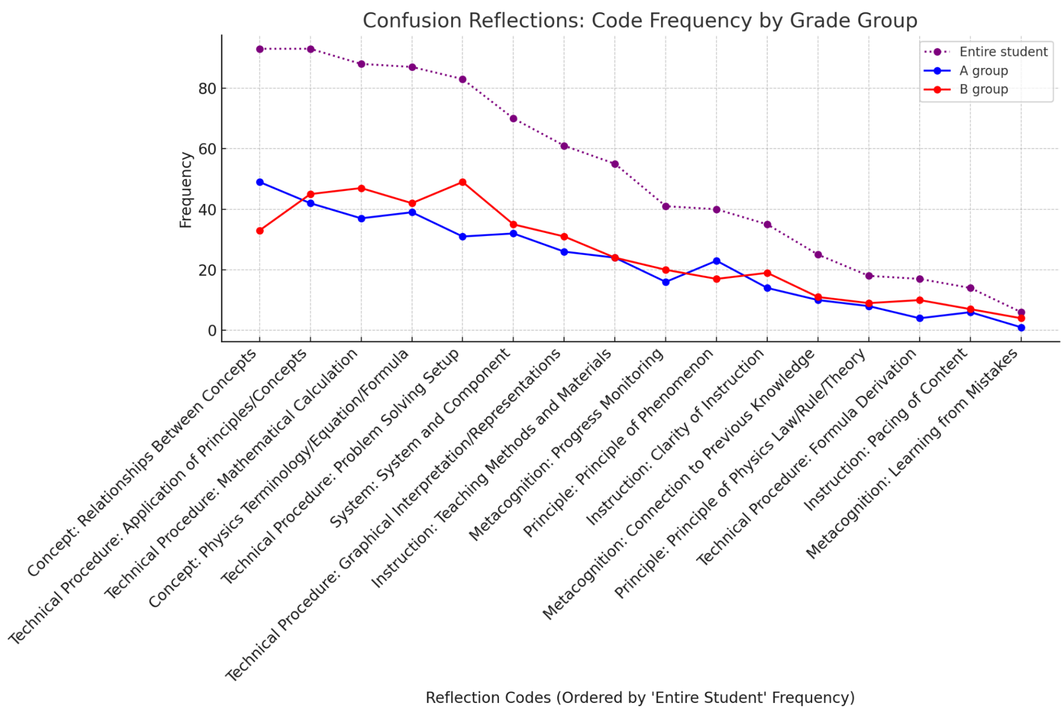

Figure 1. Code frequency observed in confusion reflections

Figure 1 shows the frequency of each code observed in confusion reflections from all students, ordered by overall frequency to answer RQ1. To address RQ2, blue and red lines were added to indicate the frequency of codes for the A and B groups, respectively.

High-frequency codes (≥80 occurrences) included *Concept: Relationships Between Concepts* (*n* = 94), *Technical Procedure: Application of Principles/Concepts* (*n* = 91), *Technical Procedure: Mathematical Calculation* (*n* = 89), *Concept: Physics Terminology/Equation/Formula* (*n* = 87), and *Technical Procedure: Problem-Solving Setup* (*n* = 83). Mid-frequency codes (40–79 occurrences) included the following: *System: System and Component* (*n* = 70), *Technical Procedure: Graphical Interpretation/Representations* (*n* = 60), *Instruction: Teaching Methods and Materials* (*n* = 54), *Metacognition: Progress Monitoring* (*n* = 41), and *Principle: Principle of Phenomenon* (*n* = 40). Low-frequency codes (<40 occurrences) included the following: *Instruction: Clarity of Instruction* (*n* = 35), *Metacognition: Connection to Previous Knowledge*

(n = 25), *Principle: Principle of Physics Law/Rule/Theory* (n = 18), *Technical Procedure: Formula Derivation* (n = 17), *Instruction: Pacing of Content* (n = 14), *Metacognition: Learning from Mistakes* (n = 6).

The A and B groups exhibited similar code frequencies, but some notable differences emerged. For instance, the A group demonstrated a higher frequency for *Concept: Relationships Between Concepts* (n = 49 for A group; n = 34 for B group). Conversely, the B group showed greater frequency in codes such as *Technical Procedure: Problem-Solving Setup* (n = 31 for A group; n = 49 for B group) and *Technical Procedure: Mathematical Calculation* (n = 37 for A group; n = 48 for B group).

Reflections on interesting parts of lectures

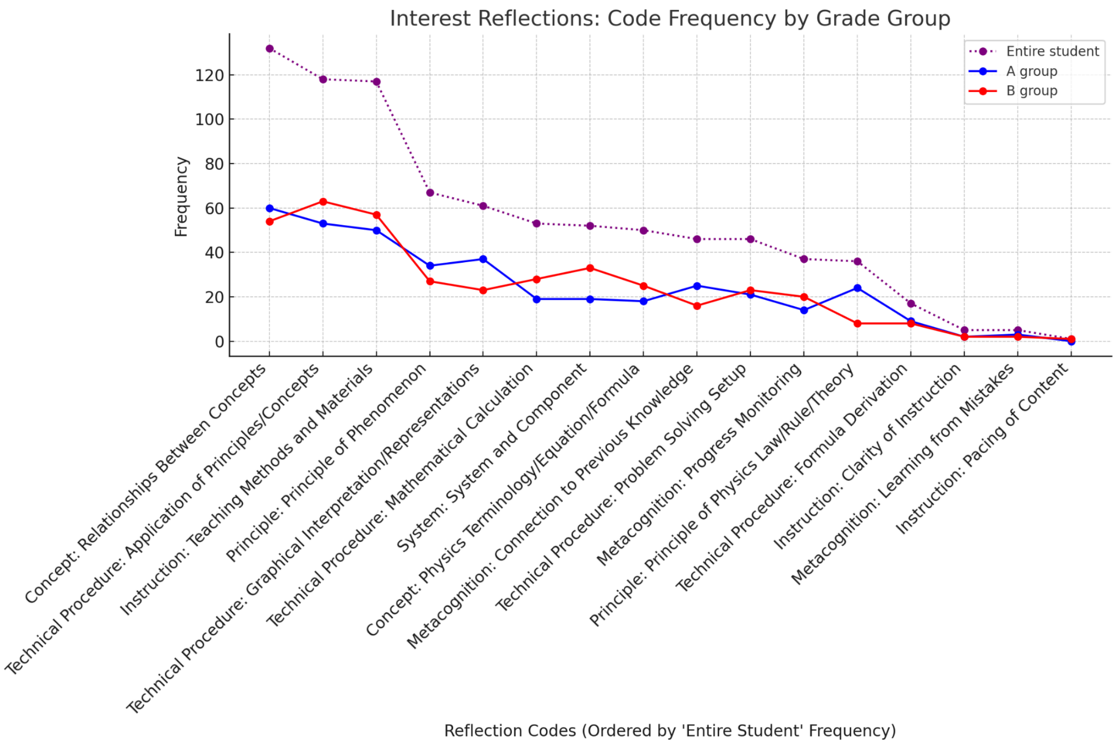

Figure 2. Code frequency observed in interest reflections

Figure 2 shows the frequency of each code observed in interest reflections from all students, ordered by overall frequency to answer RQ3. To address RQ4, blue and red lines were added to indicate the frequency of codes for the A and B groups, respectively.

High-frequency codes (≥100 occurrences) included the following (listed from highest to lowest frequency): *Concept: Relationships Between Concepts* (n = 129), *Instruction: Teaching Methods and Materials* (n = 115), and *Technical Procedure: Application of Principles/Concepts* (n = 111).

Mid-frequency codes (40-80 occurrences) included the following (ranked from highest to lowest frequency): *Principle: Principle of Phenomenon* (n = 67), *Technical Procedure: Graphical Interpretation/Representations* (n = 61), *System: System and Component* (n = 58), *Technical Procedure: Mathematical Calculation* (n = 53), *Concept: Physics Terminology/ Equation/*

Formula (n = 49), *Technical Procedure: Problem-Solving Setu*p (n = 48), and *Metacognition: Connection to Previous Knowledge* (n = 46). Low-frequency codes (<40 occurrences) included the following (ordered from highest to lowest frequency): *Metacognition: Progress Monitoring* (n = 38), *Principle: Principle of Physics Law/Rule/Theory* (n = 36), *Technical Procedure: Formula Derivation* (n = 17), *Instruction: Clarity of Instruction* (n = 5), and *Metacognition: Learning from Mistakes* (n = 4).

Compared to confusion reflections, more pronounced differences were observed between the A and B groups in their interest reflections. The A group exhibited a higher frequency in codes such as Principle: Principle of Physics Law/Rule/Theory (n = 23 for A group; n = 9 for B group), Technical Procedure: Graphical Interpretation/Representations (n = 37 for A group; n = 23 for B group), Metacognition: Connection to Previous Knowledge (n = 25 for A group; n = 16 for B group), and Principle: Principle of Phenomenon (n = 34 for A group; n = 27 for B group). In contrast, the B group exhibited a higher frequency in codes such as System: System and Component (n = 21 for A group; n = 37 for B group), Technical Procedure: Mathematical Calculation (n = 19 for A group; n = 28 for B group), Concept: Physics Terminology/Equation/Formula (n = 17 for A group; n = 25 for B group), and Instruction: Teaching Methods and Materials (n = 49 for A group; n = 56 for B group).

Similarity between the focuses of confusion and interest reflections

To answer RQ5 (i.e., How often are the focuses of reflections on confusing and interesting aspects of lectures similar to each other?), we labeled whether confusion and interest reflections left for each lecture were concerned with the same physics concepts, situations, questions, or instructional strategies. We conducted an additional analysis to better understand the overlap between confusion and interest in student reflections. As a result, we found 201 reflection submissions, 24.5 % of the total submissions, were made where a student was both confused and interested in the same or similar aspects of the lecture. Table 2 shows seven examples of such submissions where confusion and interest reflections focused on the same or similar elements of each lecture.

Table 2. Examples of Confusion and Interest Reflections Focused on Similar Concepts or Problems

Example	Confusion reflection	Interest reflection	Focus of reflection
Example 1	“when or when not to change units within wave equations”	“Usage of wave equations in music and instruments”	Both focus on wave equations, with confusion about unit conversion and interest in their application to music.
Example 2	“I think the Doppler effect was kinda confusing. Like the positive signs and the negative signs were definitely throwing me off. It would be helpful to see that in another example”	“I found the resonance in pipes to be pretty interesting, and I liked it when you made the Doppler effect sound”	Both focus on the Doppler effect, with confusion about the signs and interest in sound demonstrations.
Example 3	“(...) The first question was worded a bit weird but other than that I think it was a good exam. The second question was also nice as you could put the entire equation in terms of symbols”	“I think both problems were pretty interesting, they definitely tested our knowledge of the content well and were a good indication of the things we had learned”	Both discuss quiz problems, with confusion about wording and interest in how the problems tested knowledge.
Example 4	“How the tension multiplies across the pulley to make it easy to pull up.”	“That pulley systems make it easier to lift things up”	Both focus on pulley systems, with confusion about tension multiplication and interest in their practical use.
Example 5	“The bicycle problem, in particular, deciding which way something will move when a force is applied”	“The bicycle problem was very interesting because my perspective completely changed on how a bike moves”	Both focus on the bicycle problem, with confusion about forces and interest in how the problem changed their perspective.
Example 6	“The static equilibrium, particularly understanding where to use the lever arm”	“Using torque to calculate static equilibrium is very interesting”	Both focus on static equilibrium, with confusion about lever arm usage and interest in torque calculations.
Example 7	“(...) I was also confused why the spring force was kx and not -kx in problem 8.30.”	“I found 8.30 the most interesting because we were combining net force without a 0 acceleration. We were combining this unit and last unit's concepts.”	Both focus on question 8.30, with confusion about the spring force and interest in combining concepts from different units.

Discussion

Reflections on confusing parts of lectures

The findings of this study emphasize the importance of differentiated instruction in introductory physics education. High-performing students (A group) demonstrated a stronger focus on conceptual understanding and systems thinking while mid-performing students (B group) encountered more challenges with procedural knowledge and mathematical reasoning. Such differences suggest that tailored instructional strategies are necessary to address the unique needs of each group. Specifically, advanced conceptual exploration activities could benefit high-performing students, whereas mid-performing students may require structured scaffolding and step-by-step guidance to strengthen their procedural skills. Such differentiated approaches align with existing research on scaffolding (Belland et al., 2011) and underscore the need for balanced integration of conceptual and procedural knowledge in physics instruction (Sarwar & Trumpower, 2015; Taraban et al., 2007). Addressing these gaps through scaffolding and teacher education (Verde & Valero, 2021) could further enhance the effectiveness of such strategies.

Regarding RQ1 (i.e., What aspects of lectures do students most frequently and least frequently identify as confusing?), the analysis revealed that students frequently identified *Relationships Between Concepts* and *Physics Terminology/Equation/Formula* in the *Concept* category, as well as *Application of Principles/Concepts*, *Mathematical Calculation*, and *Problem-Solving Setup* in the *Procedure* category, as sources of confusion. Such findings indicate that students struggle with both the conceptual understanding of physics knowledge and the practical application of that knowledge. Such challenges are consistent with prior research, which revealed difficulties in conceptual integration and procedural execution in physics education (Salameh et al., 2017; Volfson et al., 2019). Meanwhile, low-frequency codes included *Learning from Mistakes* and *Progress Monitoring* under the *Metacognition* category. Such low frequency suggests that instructional strategies could better support students' metacognitive development. Empirical evidence from our study aligns with prior literature (Nurulain Mohd Rum & Zolkepli, 2018), emphasizing the need for structured opportunities for reflection to foster metacognitive skills (Bell et al., 2018).

Regarding RQ2 (i.e., How is students' academic performance related to the content of their reflections on confusing parts of lectures?), our findings reveal distinct patterns between high-performing (A group) and mid-performing (B group) students. High-performing students reported higher frequencies of reflections on *Relationships Between Concepts* and *System and Component*, which may suggest a focus on abstract conceptualization and systems thinking. On the other hand, mid-performing students showed challenges with *Problem-Solving Setup* and *Mathematical Calculation*, pointing to difficulties with procedural fluency and mathematical reasoning. Such challenges support the importance of addressing diverse cognitive strategies (Gaigher et al., 2007), with high-performing students benefiting from open-ended, interdisciplinary problems and mid-performing students requiring scaffolded support. Such targeted approaches align with findings from studies like Belland et al. (2011) and Menekse (2020) on the effectiveness of long-term scaffolding and further emphasize the need for differentiated instruction in physics education.

Reflections on interesting parts of lectures

In addition to the findings from confusion reflections, the findings from interest reflections reveal that students' engagement with lectures is strongly influenced by their ability to connect physics concepts, understand their applications, and experience effective instructional strategies. High-frequency codes such as *Relationships Between Concepts*, *Teaching Methods and Materials*, and *Application of Principles/Concepts* highlight the elements that students find most engaging. Such reports underscore the importance of integrative thinking and contextualized teaching in fostering interest in physics lectures. The overlap between sources of interest and confusion, particularly in *Relationships Between Concepts* and *Application of Principles/Concepts*, suggests that the same aspects of lectures can challenge and captivate students simultaneously. Such duality points to opportunities for instructional strategies that not only address student confusion but also amplify their interest by emphasizing real-world relevance and conceptual connections (Nashon & Anderson, 2013; Vogelzang et al., 2021).

Regarding RQ3 (i.e., What aspects of lectures do students most frequently and least frequently identify as interesting?), students were particularly engaged by connections between physics concepts and their applications to specific scenarios. As evidenced in previous studies (e.g., Henderson et al., 2011; Means et al., 2016), lectures that emphasize the application of physics concepts can significantly enhance engagement, even in introductory courses focused on knowledge delivery rather than experiments or project-based learning. Instructional strategies that emphasize interactive and contextualized learning can further increase interest in less frequently identified aspects, such as *Learning from Mistakes* and *Progress Monitoring* in the *Metacognition* category. Integrating metacognitive elements, such as reflecting on problem-solving strategies or learning from errors, could promote student interest and engagement in underestimated areas (Callender et al., 2016; Nielsen et al., 2009).

Regarding RQ4 (i.e., How is students' academic performance related to the content of their reflections on interesting parts of lectures?), distinct differences emerged between high-performing (A group) and mid-performing (B group) students. High-performing students demonstrated greater interest in *Principle of Physics Law/Rule/Theory* and *Graphical Interpretation/Representations*. Such students may engage more deeply with abstract principles and data visualization, reflecting higher-order thinking skills (Hung et al., 2006). Redish (1994) notes that students' understanding of physics is enhanced by their ability to build mental models of abstract principles and interpret data representations, skills that are more prevalent in high-performing students. In contrast, mid-performing students reported greater interest in *Teaching Methods and Materials* and *System and Components*. Such a report may indicate a focus on instructional clarity and structural support. Such reliance on external guidance to navigate complex content implies a potential need for targeted teaching strategies that balance clarity and conceptual exploration to support mid-performing students.

Similarity between the focuses of confusion and interest reflections

Regarding RQ5 (i.e., How often are the focuses of reflections on confusing and interesting aspects of lectures similar to each other?), 24.5% of student reflections revealed an overlap between confusion and interest. Such overlap suggests that confusion and interest are not entirely independent and may share a cognitive or affective basis, which is likely to influence student engagement with the material. While confusion is often viewed as a negative state, it can catalyze deeper engagement when paired with the motivation to resolve misunderstandings. D'Mello (2013), for example, discusses how confusion, along with other affective states, fosters subgoal creation during learning processes. Although not directly linking confusion and interest, this work emphasizes that confusion can play a constructive role in cognitive engagement, especially in problem-solving contexts.

Similarly, Fayn et al. (2019) explored the role of personality traits, such as openness/ intellect, in shaping the relationship between cognitive engagement and emotions during complex tasks. Their findings suggest that individuals with higher openness may interpret challenging situations, often associated with confusion, as intellectually stimulating, leading to positive engagement. While the study does not explicitly address confusion and interest together, it provides a framework for understanding how emotional and cognitive factors intertwine in learning. Additionally, Jirout (2020) focuses on curiosity as a driver for inquiry and engagement. The study proposes that states like confusion can initiate information-seeking behaviors. Such perspectives do not directly address the relationship between confusion and interest. However, they still can support the idea that both states are integral to fostering more profound learning, mainly when students engage with challenging or complex material. This aligns with the observed overlap in student reflections and suggests that confusion and interest may often coexist and contribute to meaningful engagement.

Limitations and future works

Our study has three limitations that provide opportunities for future research. First, we did not collect demographic data such as students' gender, age, or prior academic performance because such information was not necessary to answer our research questions. Additionally, we did not gather data on students' majors because they took a first-year STEM course designed for students from various disciplines and without majors being decided rather than an advanced course targeting a specific major or department. However, while such data was not the focus of the current study, including demographic information in future research could offer deeper insights into potential differences in how diverse student groups engage with and reflect on physics concepts. For instance, variations in the concepts students find most interesting might emerge differently based on their backgrounds or academic trajectories. Such findings can provide valuable information for developing tailored instructional strategies.

Second, we collected the data from a single course taught by one instructor, limiting our findings' generalizability. Expanding the present research to include similar courses taught by different instructors or at other institutions could help validate and broaden the applicability of our results. Additionally, analyzing longitudinal data from the same course taught by the same instructor over several years could shed light on how instructors evolve their teaching strategies to address students' confusion and foster interest. Such analyses could provide additional valuable insights into the effectiveness of adaptive teaching methods over time.

Third, using the app was optional for students, meaning the data collected may not fully represent the entire class. Students with lower engagement levels were likely to opt out of using the app, potentially introducing selection bias into the findings. Future research could focus on strategies to increase student participation, such as integrating reflection activities directly as a course requirement to collect data from all students. Such an approach would ensure a more representative understanding of classroom dynamics. Including reflections from less-engaged students could provide a richer and more comprehensive perspective on supporting a broader range of learners in introductory physics courses, addressing their unique challenges and needs.

In future work, we can explore the similarity of focus between confusion and interest reflections in greater detail. For instance, it would be valuable to classify the types of similarities observed. As illustrated in Table 2, Example 4 demonstrates reflections centered on specific quiz problems, with confusion about wording and interest in how the problems assessed knowledge. In contrast, Example 7 shows reflections focusing on the same physics concept, with confusion about lever arm usage and interest in torque calculations related to static equilibrium. Such examples suggest variations like the overlap, whether tied to physics concepts or specific tasks. Developing a classification system to differentiate these similarities could provide deeper insights into how confusion and interest are interconnected and guide more targeted instructional strategies. Additionally, future studies could incorporate qualitative approaches, such as interviews or focus groups, to better understand students' experiences when confusion and interest overlap. Such insights could provide richer data to interpret self-reflections and offer practical guidance to customize instructional strategies to support students in navigating and benefiting from such overlapping cognitive-affective states.

Implications for physics educators in higher education

As a result of our study, we propose three implications that are extendable beyond introductory physics courses and broadly applicable to engineering and STEM education. The implications address challenges common to large lecture courses by emphasizing the significance of 1) fostering metacognitive skills, 2) leveraging student interest, and 3) stimulating the productive potential of overlaps between confusion and interest. While grounded in physics education, the findings provide transferable practices to improve student engagement and learning outcomes across related fields, including engineering education.

Implication #1: Fostering metacognitive skill development through scalable practices

Teaching hundreds of students in a large lecture format often limits the time and resources educators can dedicate to fostering metacognitive skills, such as reflection and progress monitoring. In the present study, the low frequency of metacognitive reflections suggests that such practices are underutilized, likely due to the logistical constraints of managing large classes. Yet, fostering metacognitive skills is critical in introductory physics courses, as such courses provide foundational knowledge that students will rely on in more advanced coursework. Without adequate metacognitive development, students risk barely passing the course without being well-prepared for the complex concepts and problem-solving required in the later stages of their education (Chan & Lee, 2021). Low-performing students tend to be underdeveloped in their metacognitive monitoring, which negatively impacts their exam preparation, study strategies, and academic performance (Morphew, 2024).

To address this, educators can integrate short, structured reflection prompts into existing lecture or homework formats (Guo, 2022). For example, prompts such as "What was the most challenging part of today's lecture, and how would you approach it differently next time?" can encourage students to think critically about their learning process without adding a significant workload for educators. Additionally, leveraging learning management systems (LMS) can enable the scalable collection and analysis of student reflections. This allows instructors to identify common patterns in student responses and provide targeted feedback or adjustments to their teaching strategies.

Implication #2: Leveraging students' interest to drive engagement in a distracting lecture room

Maintaining student engagement in large lecture environments poses a significant challenge. Educators must contend with distractions and limited opportunities for direct interaction with students. Such a challenge can be addressed through findings from the current study–students are most engaged when lectures emphasize relationships between concepts, applications to real-world scenarios, and effective teaching methods and materials. Such aspects not only capture students' attention but also make abstract physics concepts more relatable and meaningful.

Including real-world examples and interdisciplinary problems can help students connect physics principles to their everyday lives and future STEM careers. For instance, discussing how physics concepts apply to engineering designs or environmental solutions can make lectures more relevant and stimulating. Short video demonstrations or simulations can further enhance engagement by visually illustrating the application of physics concepts. Incorporating new content is particularly effective in large classes, where hands-on demonstrations may be logistically challenging. Physics educators can create an immersive learning experience that captures students' interest by integrating visually and contextually engaging materials.

Implication #3: Stimulating both confusion and interest in introductory physics concepts

When appropriately guided, confusion can serve as a valuable precursor to interest by sparking curiosity and motivating students to resolve misunderstandings. Physics educators can leverage the overlap between confusion and interest to design instructional strategies that simultaneously challenge students and maintain their engagement. To do so, collecting, capturing, and analyzing the focus of student reflections on confusion and interest will provide critical insights into areas where learning is both difficult and stimulating. By examining how confusion transitions into interest, educators can refine lessons to emphasize these moments of cognitive engagement.

While confusion is a natural part of learning complex physics concepts, educators take significant roles in helping students channel such confusion productively. By creating opportunities for exploration and providing timely scaffolding, instructors can guide students to transform confusion into sustained interest. Such an approach not only supports a deeper understanding of physics concepts but also creates a positive learning environment where academic curiosity and struggles are valued. Such strategies can contribute to long-term interest in physics and related disciplines, encouraging students to engage more fully with challenging material.

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